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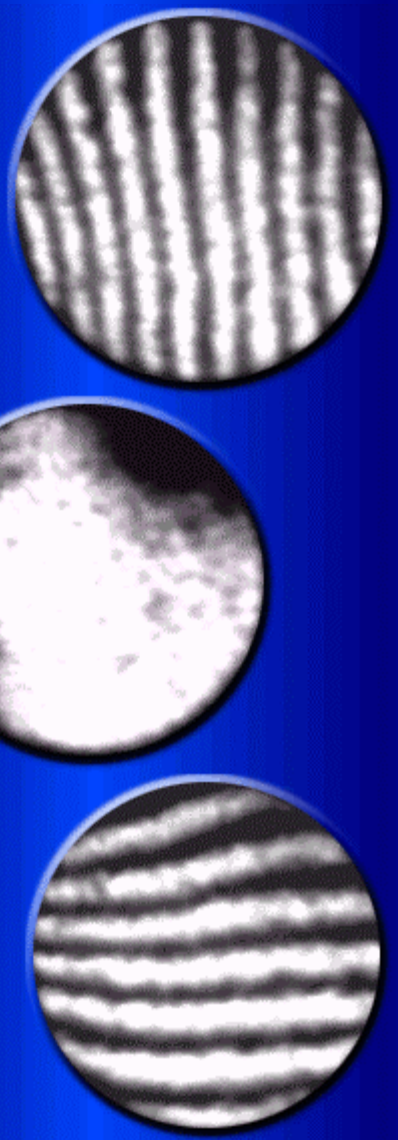

Developments in Ultra Lighweight Membrane Optical Elements

Presented by Brian Patrick

Technology Days MSFC

May 23, 2002

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Membrane Material for Optical Applications

CP1™ (Clear Polyimide)

- **Developed by NASA Langley specifically for Space Applications**
- **Material Synthesized by SRS Under Exclusive License from NASA. (End to End Quality Control)**
- **Film Manufacturing Process Results in Very Homogenous Film Properties**
- **Wide Range of Operating Temperatures (Cryogenic - 250C)**
- **Resistant to UV Radiation**
- **Film Solubility Enables Advanced Casting and Surface Replication Manufacturing Techniques**

Polymer Manufacturing Facilities

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Primary Requirements for Precision Membrane Optics

Surface Finish

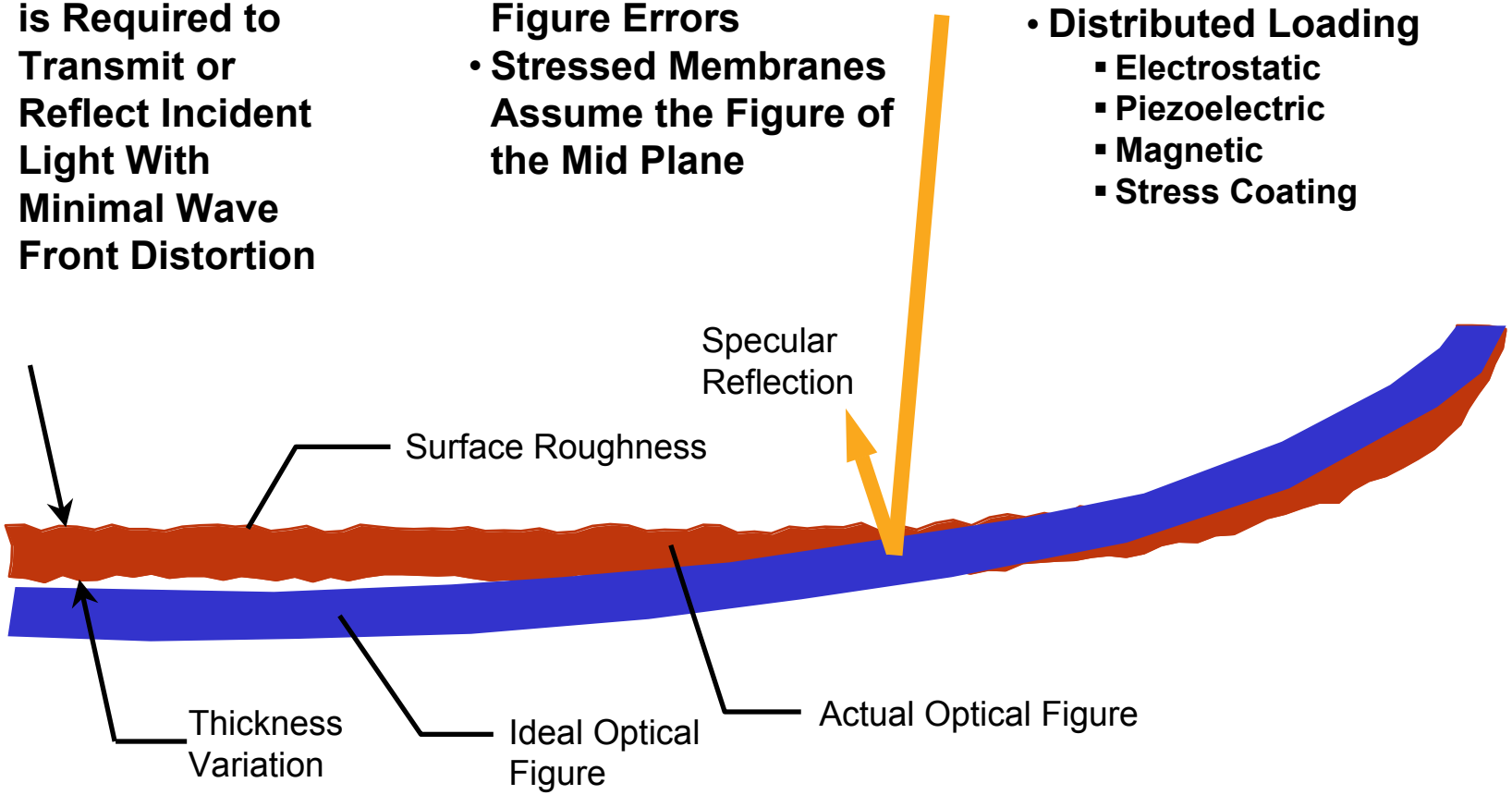
- A Highly Polished Specular Surface is Required to Transmit or Reflect Incident Light With Minimal Wave Front Distortion

Uniform Thickness

- Thickness Variations will Contribute to Figure Errors
- Stressed Membranes Assume the Figure of the Mid Plane

Figure Control

- Boundary Control
  - Rigid Ring
  - Compliant Ring
  - Active Tuning
- Distributed Loading
  - Electrostatic
  - Piezoelectric
  - Magnetic
  - Stress Coating



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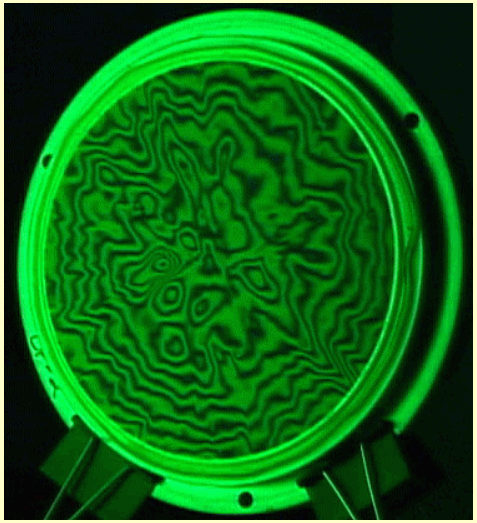
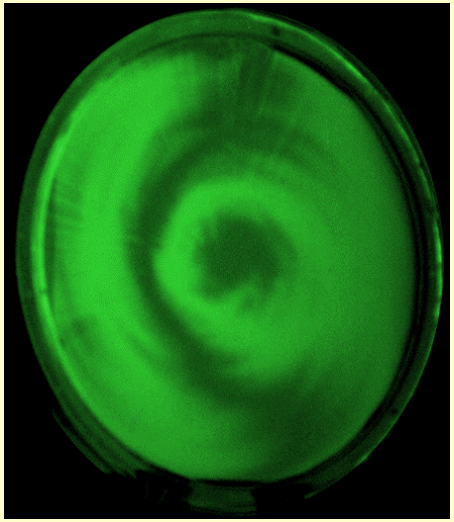
Membrane Thickness Variation Process Refinement

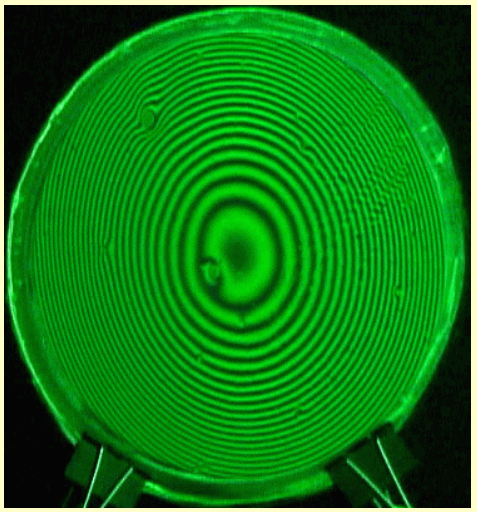
- Modifications to casting process has resulted in drastic improvement in thickness variation present on both flat and curved substrates.
- Sub-Wavelength Thickness Variation Demonstrated on Apertures Up To 0.5-meters.



Typical Membrane Material



Minimized Thickness Variation



Uniform Thickness Variation

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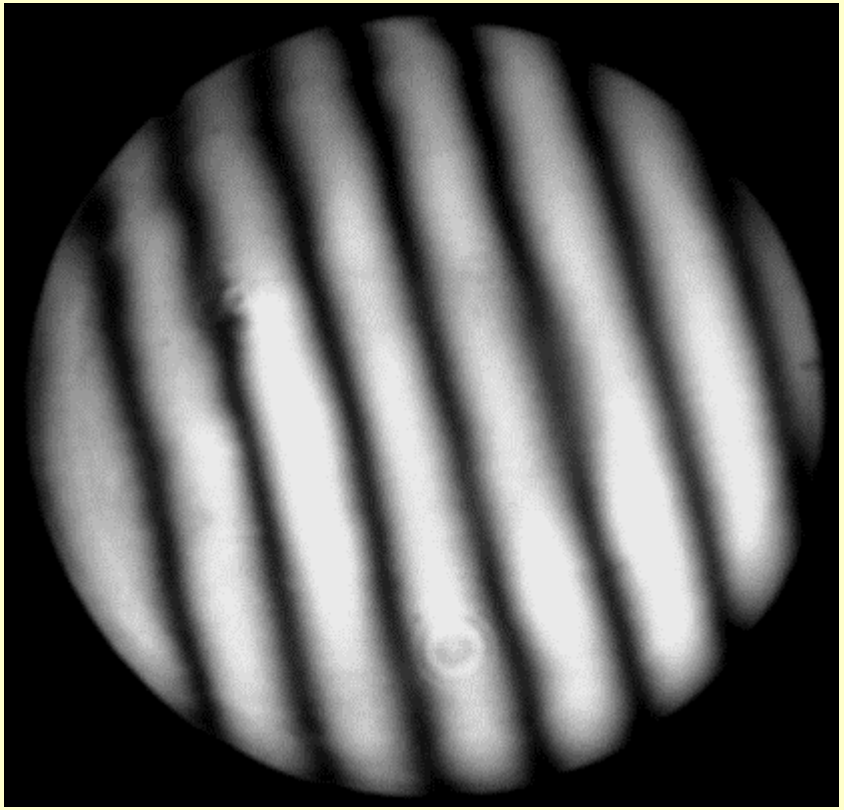
Membrane Thickness Variation Process Refinement

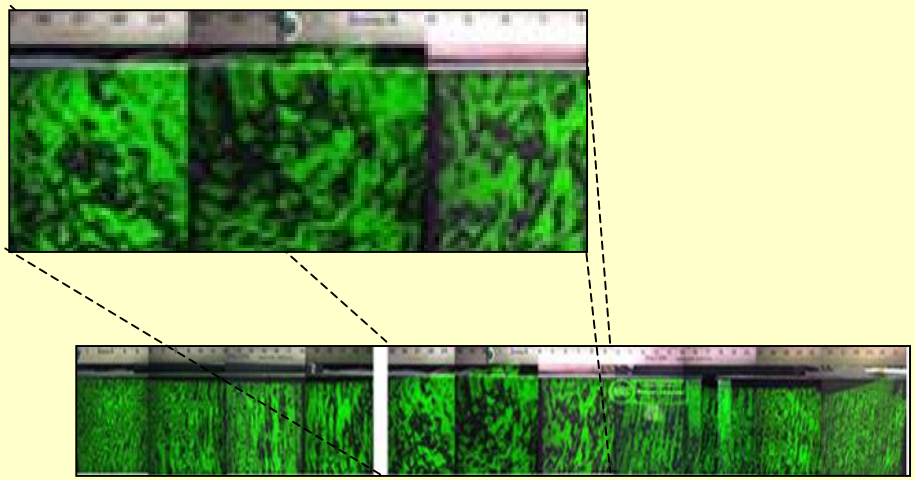


Double-pass Interferogram of a 10cm Sample of CP-1

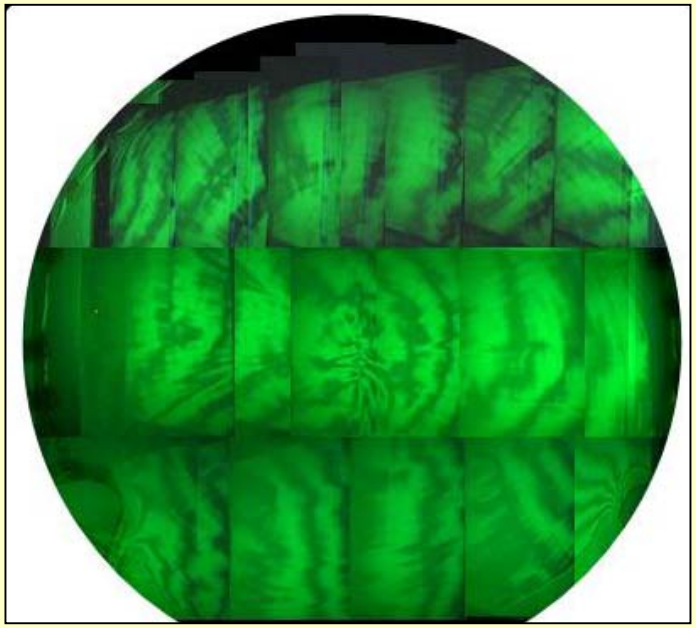
Thickness Uniformity ~1/20 wave rms.

SRS Large-Scale Casting System

- New large-scale membrane facility has been installed at SRS and initial castings have shown similar success in thickness variation. Expandable up to 3-meter diameter castings.
- Currently Thickness Variation has been minimized to ~2 waves of error over 1.5-meters.



Center Strip of1.5-meter Membrane Casting Prior to Facility Upgrade



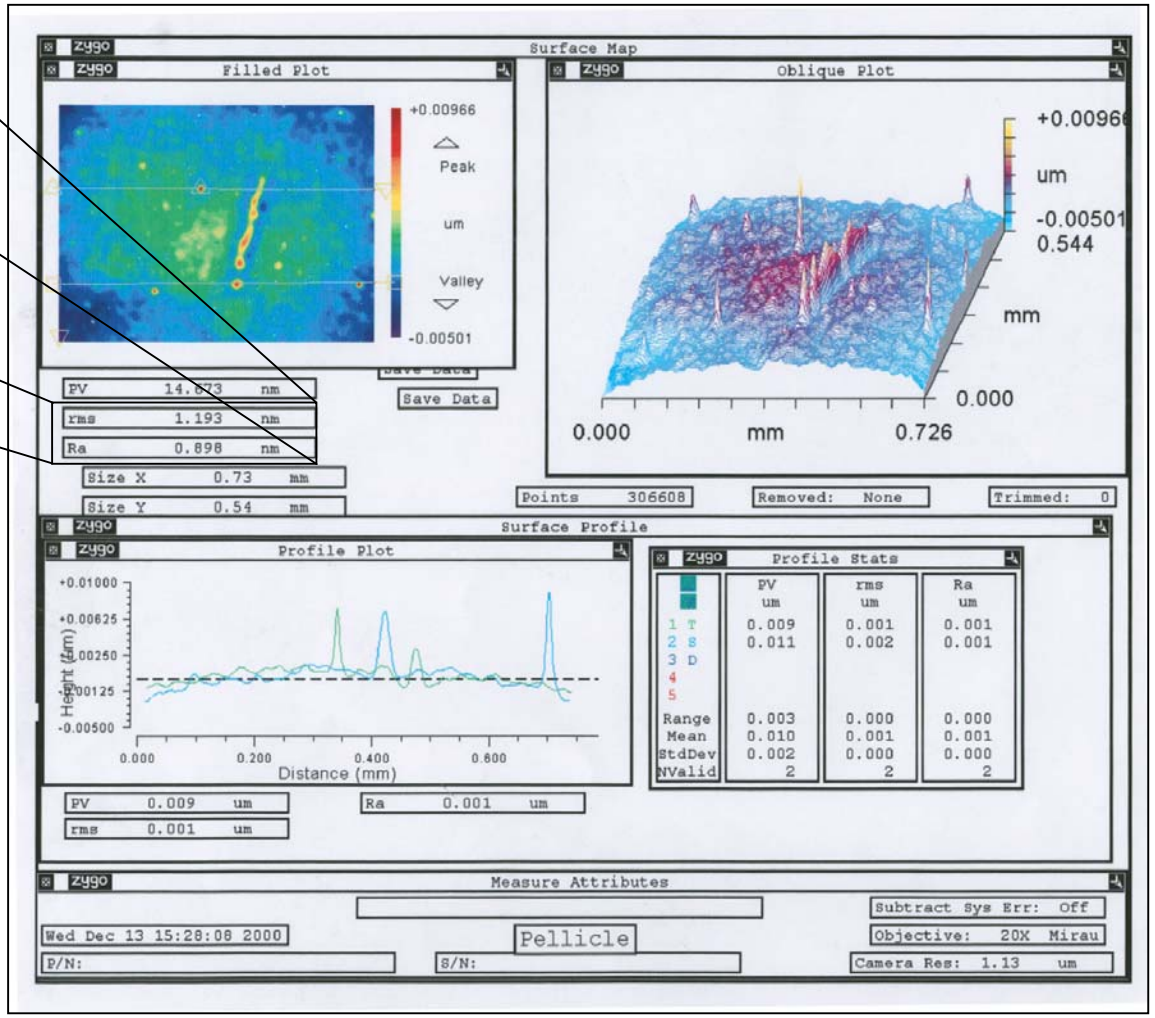
Thickness Variation Composite of 1.5-meter diameter CP-1 Membrane revealing only ~2 waves of error.

Surface Roughness for SRS CP1™ Cast Membrane Films

www.SRS.com

rms	1.193	nm
Ra	0.898	nm

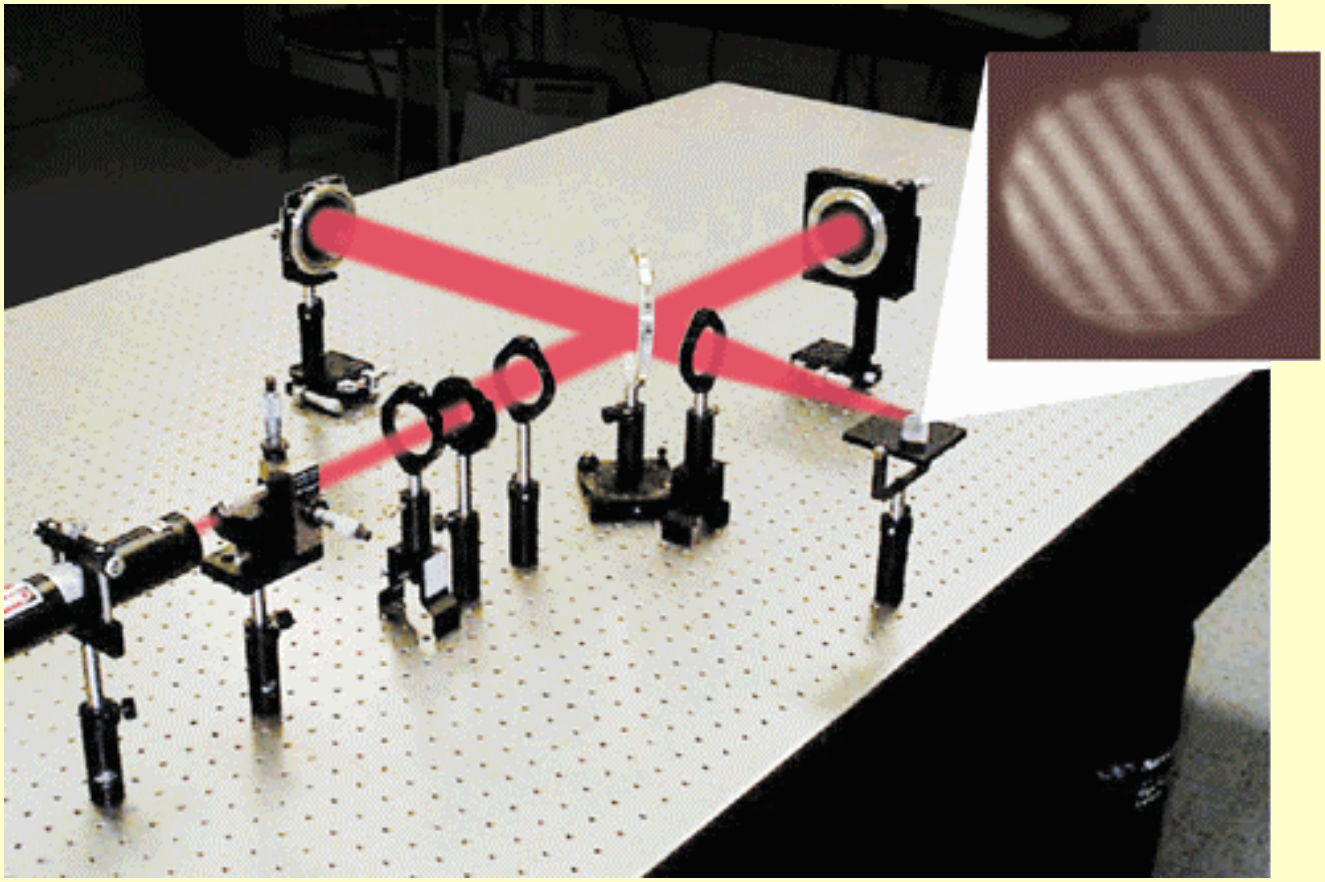
- 1.193 nm RMS Surface Roughness Demonstrated on 0.5 Meter Test Article
- Surface Roughness is Achievable on Precision Mandrel Replicated Films and Large Scale Net-Shape Films
- Air-Side of Membrane typically has superior surface finish than the casting substrate.



Surface Topography for SRS CP1™ Sample Cast from a Non-Precision Float Glass Substrate

Membrane Shape Management - Flats

Precision Thin Film Pellicles for Optical Bench Applications



Twyman-Green Interferometer consisting of CP1 beam splitter and mirrors

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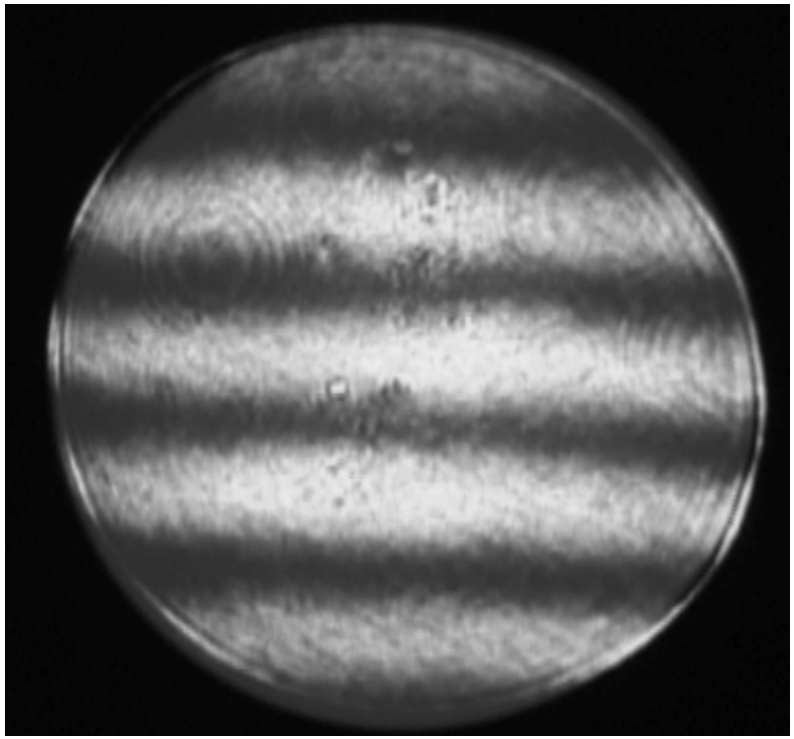
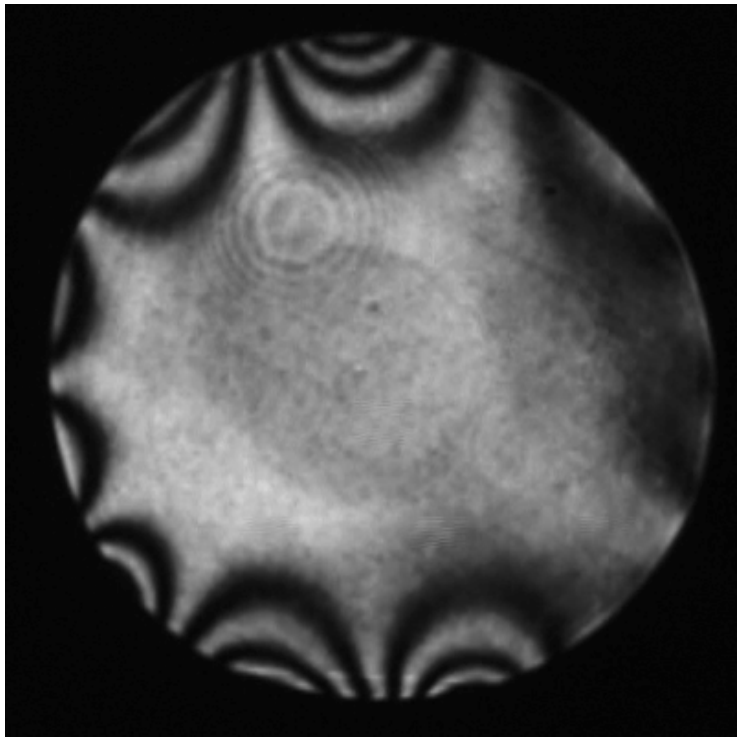
Membrane Shape Management – Curved, Stress Coated Membranes



Interferogram of 1.5-inch diameter central region of uncoated membrane



Interferogram of 4-inch diameter central region of uncoated membrane

Membrane SRS 0107-014

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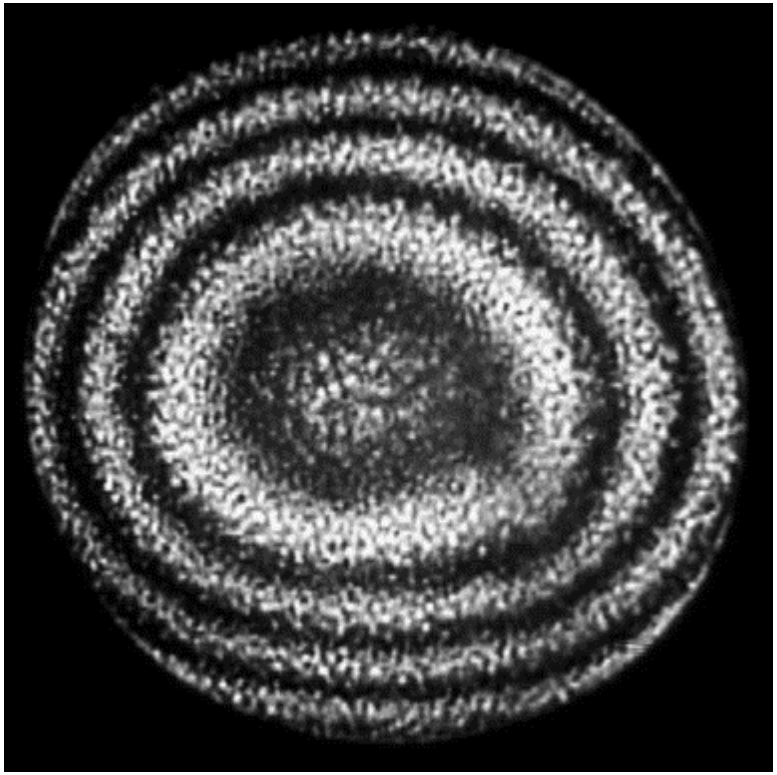
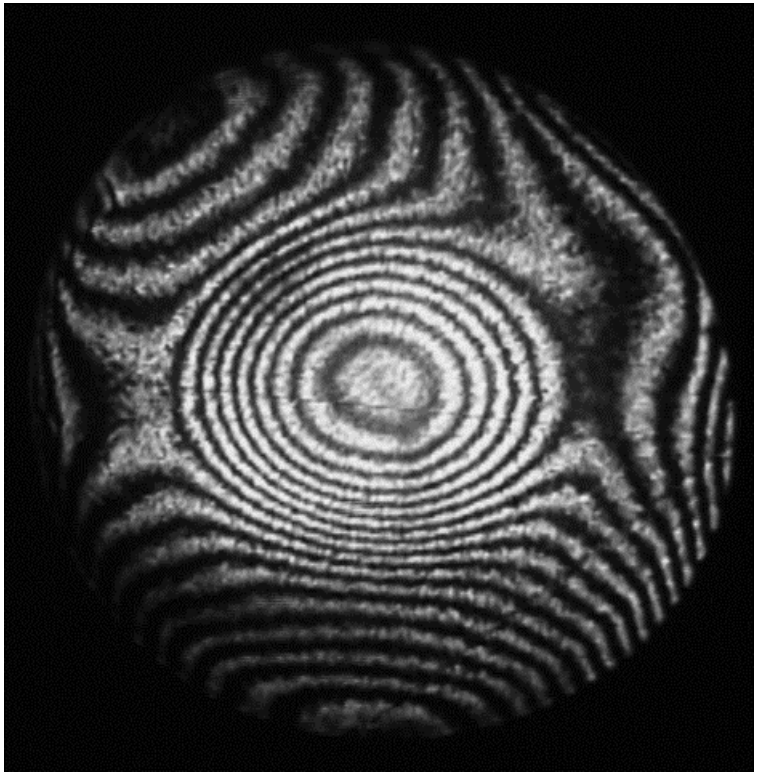
Membrane Shape Management – Curved, Stress Coated Membranes



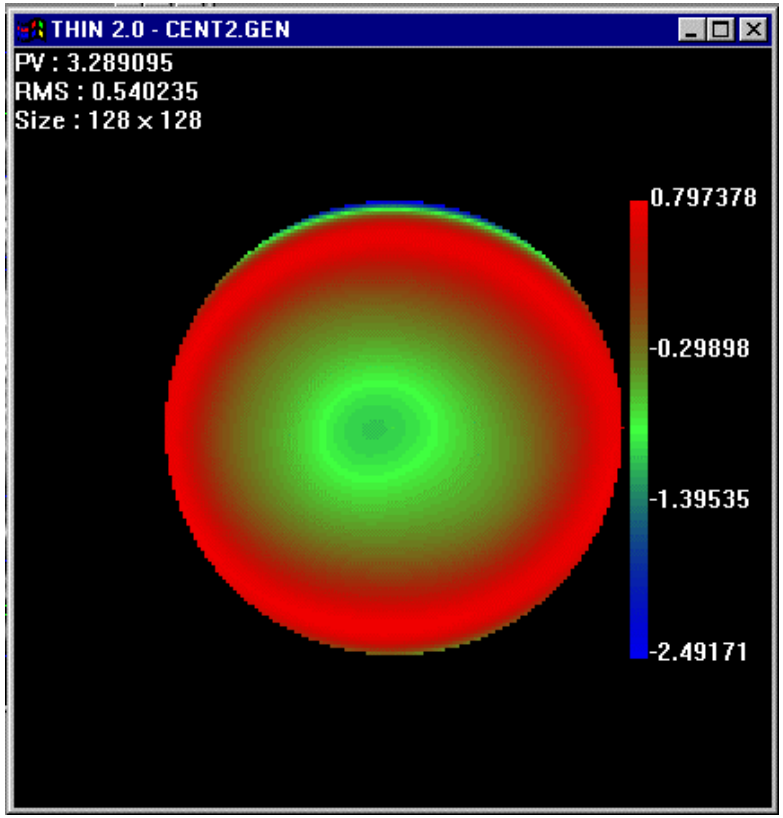
Interferogram of 1.5-inch diameter central region of coated membrane



Interferogram of 4-inch diameter central region of coated membrane

Membrane SRS 0107-009

Membrane Shape Management – Curved, Stress Coated Membranes



Analysis of 1.5-inch diameter central region of coated membrane

Focus Term

Z3:	0.706139

ZERNIKE TERMS

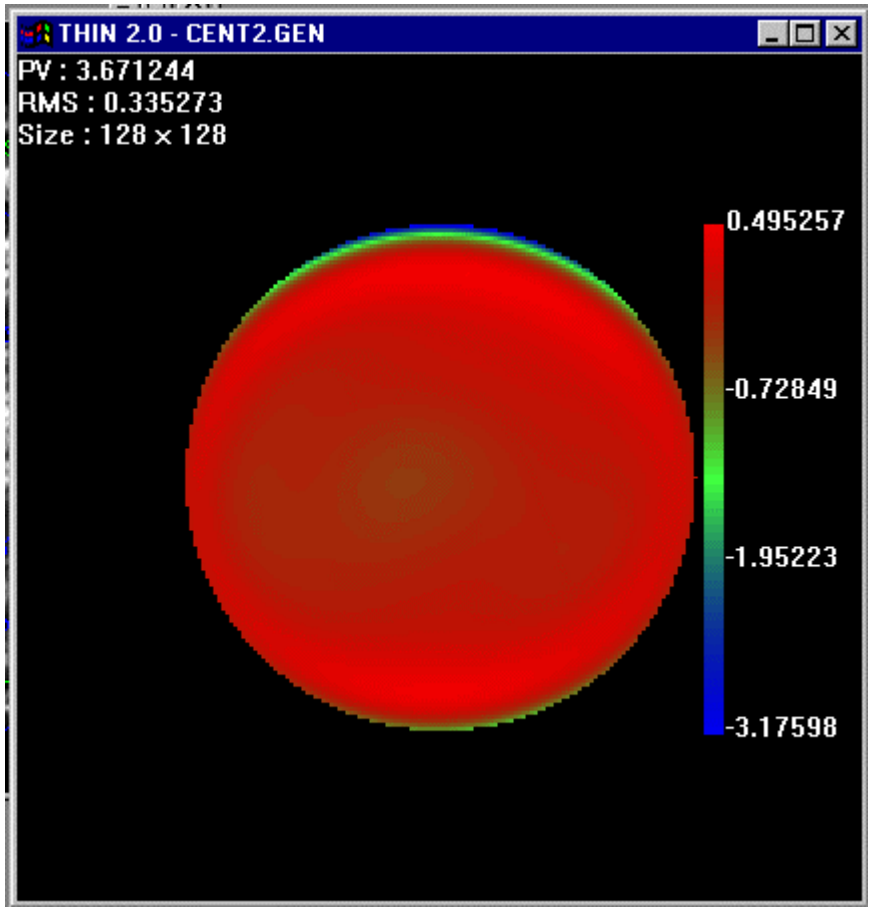
Polynomial List

Z0:	0.763890	Z10:	-0.15240	Z20:	0.397790	Z30:	-0.04050	Z40:	0.000000
Z1:	0.066319	Z11:	0.519079	Z21:	-0.03450	Z31:	0.185340	Z41:	0.000000
Z2:	0.115139	Z12:	0.007569	Z22:	-0.02439	Z32:	-0.05059	Z42:	0.000000
Z3:	0.706139	Z13:	-0.01389	Z23:	0.194029	Z33:	0.045030	Z43:	0.000000
Z4:	0.127880	Z14:	0.307389	Z24:	-0.27649	Z34:	0.083629	Z44:	0.000000
Z5:	-0.02439	Z15:	-0.35420	Z25:	-0.01690	Z35:	-0.04679	Z45:	0.000000
Z6:	-0.08930	Z16:	-0.10450	Z26:	-0.00120	Z36:	-0.00619	Z46:	0.000000
Z7:	0.345609	Z17:	0.017550	Z27:	-0.07960	Z37:	0.000000	Z47:	0.000000
Z8:	-0.40770	Z18:	0.024539	Z28:	0.011409	Z38:	0.000000	Z48:	0.000000
Z9:	0.028049	Z19:	-0.04139	Z29:	-0.00419	Z39:	0.000000		

All Data in Waves @ 633nm

Membrane Shape Management – Curved, Stress Coated Membranes

Focus Term Removed

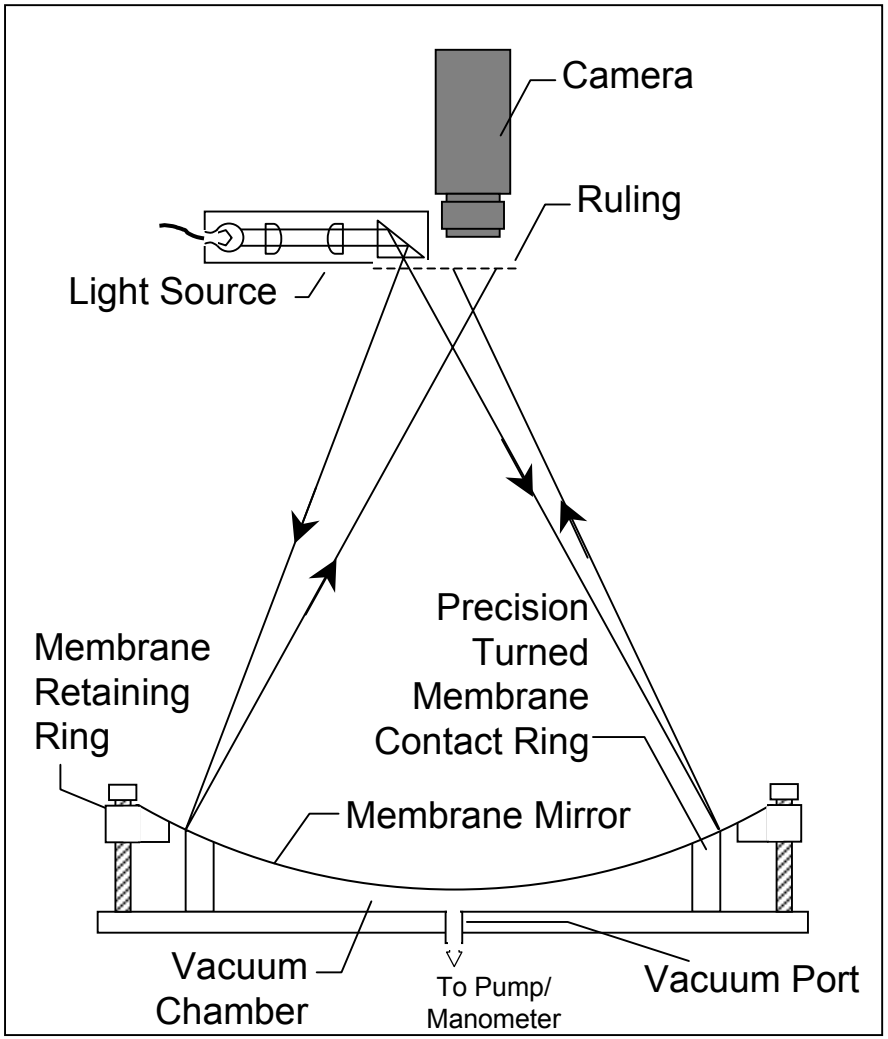


All Data in Waves @ 633nm

Membrane Shape Management – Curved, Net Shape

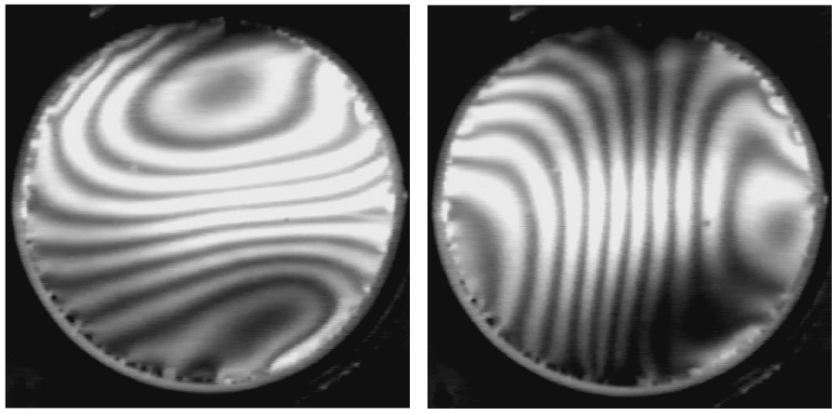
- Replicated Spherical Optics Test
- 0.5-meter f/1.87 membrane
- Slight Vacuum used to seat film onto mount
- Ronchi Grating used to test membrane

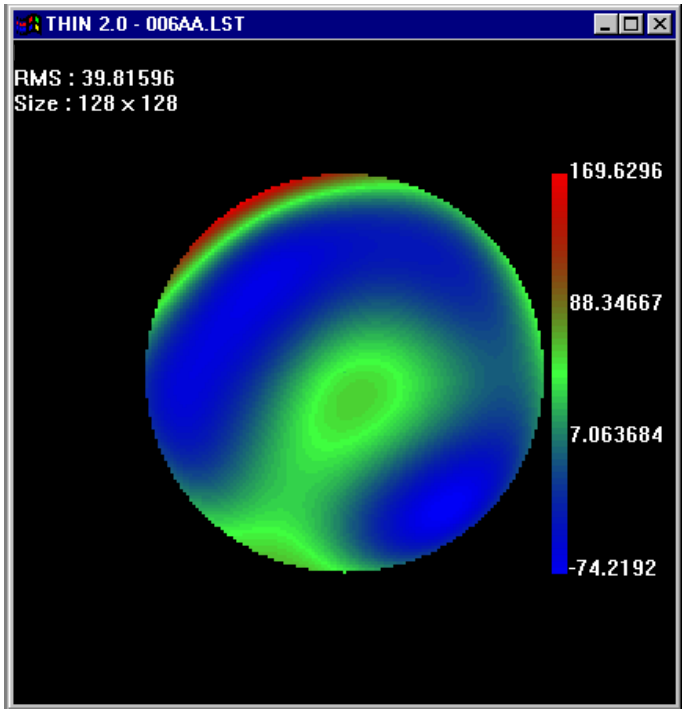
16-Inch Spherical Test Article



Membrane Shape Management – Curved, Net Shape

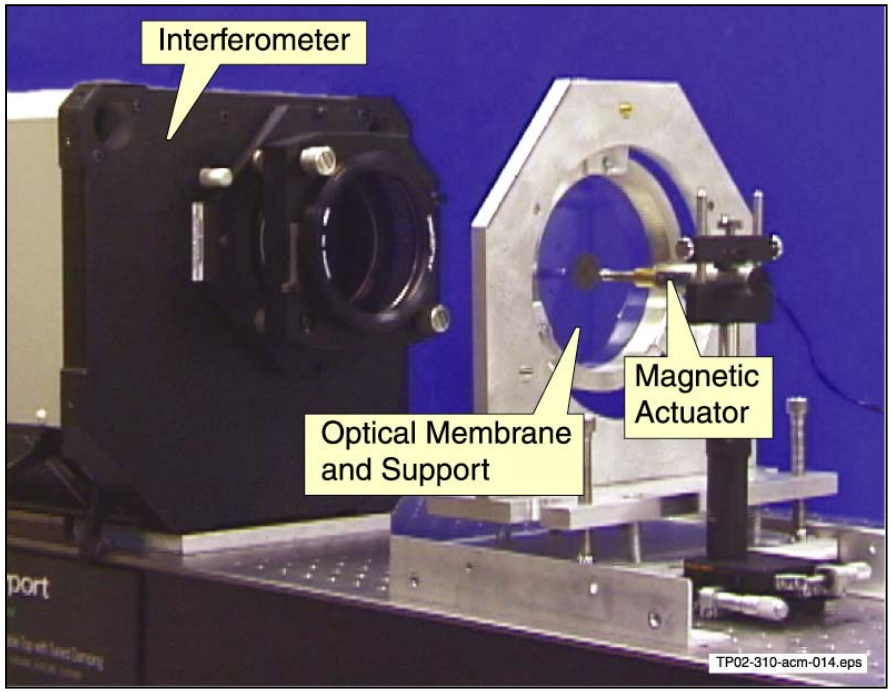
- 0.5 lp/mm grating used at orthogonal positions
- Edge Loads and Out of Plane Loads Change Figure
- Analysis Shows Figure Error.
  - 39 micron RMS figure error for full aperture.
  - 7 micron RMS figure error for 20-cm aperture
  - Majority of figure error is membrane mounting non-uniformities and slight surface roughness on diamond turned seating ring on mount.
  - This figure error begins to approach the available correction range of adaptive optic systems currently in use such as the Real-Time Holography developed by the AFRL.



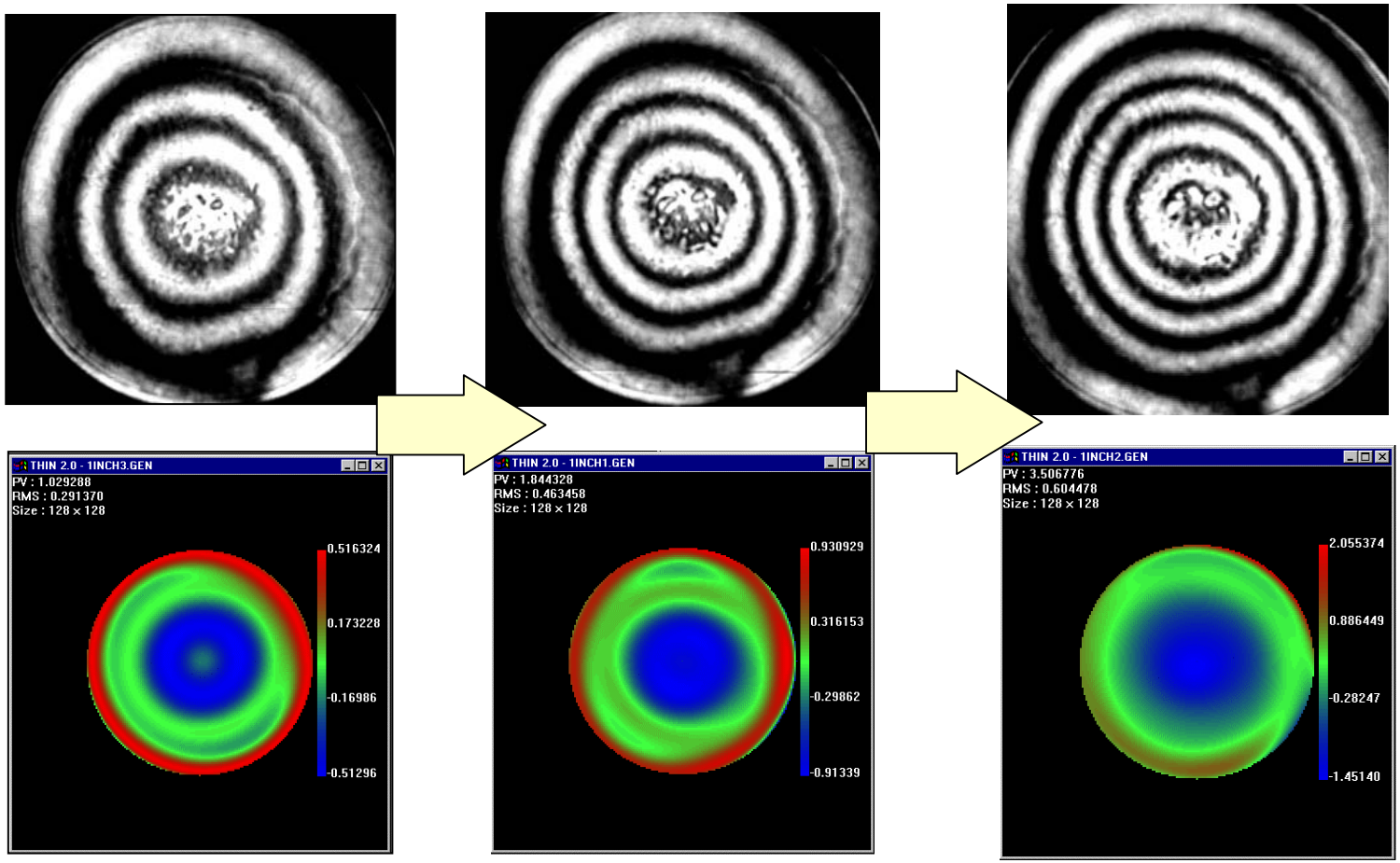


Membrane Shape Management – Curved, Magnetic

- SRS membrane has central area coated with magnetic material.
- The membrane is flat and of optical quality demonstrating ~1/4wave flatness in central area.
- A magnetic actuator is placed behind the membrane.
- System is placed in ZYGO interferometer setup for surface figure measurement.



Membrane Shape Management – Curved, Magnetic



- As actuator moves closer curvature is produced in the membrane, primary error compared to flat is mainly Focus, some spherical..

Conclusions

- Membrane Optical Elements, With Areal Density of 0.05 Kg/m^2 (Unsupported), Have Been Manufactured With Surface Finish and Thickness Tolerance Sufficient for Precision Optical Applications
- Practical Flat Membrane Elements Are Available Now. Additional Research Is Under way to Further Address Lightweight Support and Figure Control for Curved Optical Elements.
- Scaling Technology Exists to Create Very Large Aperture Membrane Elements of Optical Quality.
- Funding Sources – AFRL & NASA/MSFC